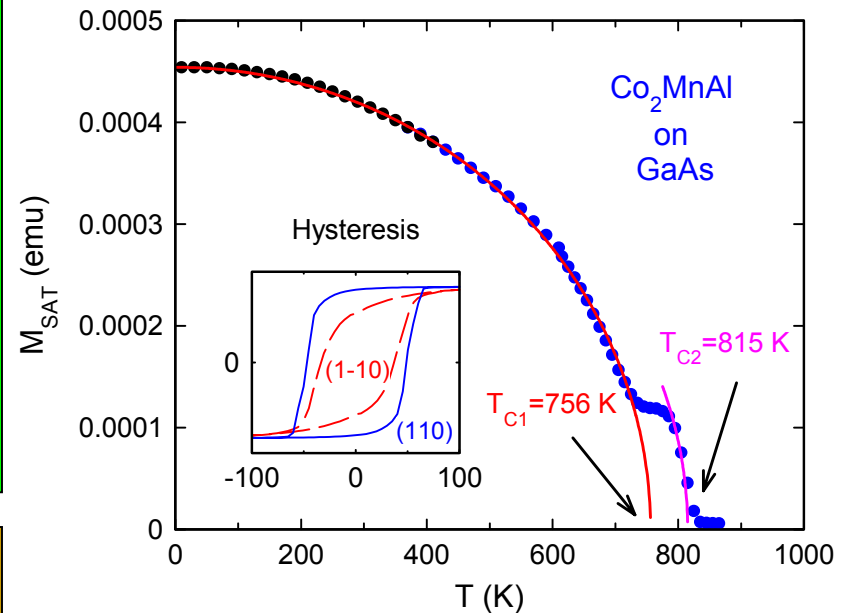


# Half-Metals on Semiconductors for Spin Electronics

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➤ Although modern electronic devices rely on the **charge** of electrons, scientists envision that future electronic devices for information technology will take advantage of the **spin** property of electrons. The term spin refers to the angular momentum of the spinning charge of the electron. The spin results in a magnetic moment attached to the electron. One application of a spin electronic or “**spintronic**” device is in a quantum computer – a computer which can compute functions many orders of magnitude faster than current binary-based computers.

➤ Our objective is to synthesize new spintronic materials which are compatible with current semiconductors such as Si and GaAs. We have found that the ferromagnetic half-metal **Co<sub>2</sub>MnAl** is compatible with GaAs and has nearly the same lattice constant. The figure shows how the magnetic moment at saturation decreases for increasing temperature, but remains ferromagnetic well above room temperature (300K).



➤ Current investigations are aimed at injecting spin-polarized electrons from the ferromagnetic  $\text{Co}_2\text{MnAl}$  layer into semiconducting GaAs to produce transistor-like devices.

One of the major requirements for future spin electronic devices is a magnetic field -- either an *effective* magnetic field from something like the spin-orbit Rashba effect, or a *direct* magnetic field produced by a ferromagnet. Direct magnetic fields are readily produced by ferromagnets, such as the transition metals cobalt, iron and nickel. However, in these materials, although the magnetic moments of the ions can be fully polarized (magnetized), the conduction electrons are far from being 100% polarized. This reduced polarization is adverse for devices requiring the injection of spin-polarized carriers. Several types of ferromagnetic materials have been used to inject spin polarized carriers into semiconductors. In contrast to the transition metals, so-called half-metals can have the electrons fully polarized. “Half-metal” refers to the fact that the material has metallic conduction for electrons of one spin direction, yet is an insulator for the other spin direction. Half metals include: the widely-used material for magnetic tapes, CrO<sub>2</sub>; and Heusler ferromagnets, such as the magnetic shape material Ni<sub>2</sub>MnGa, and also Co<sub>2</sub>MnX.

Two Heusler materials were investigated in this grant, Co<sub>2</sub>MnGa and Co<sub>2</sub>MnAl. These materials were grown epitaxially on GaAs by MBE. Magnetic measurements were used to determine the ferromagnetic Curie temperature,  $T_C \sim 800$  K. The inset of the figure shows the hysteresis at room temperature. The figure shows the magnetization versus temperature  $M(T)$ . There are several anomalies in  $M(T)$ . Notice the two-transition behavior at high temperatures. This results from a phase transition near  $T_C$ , from one crystal structure to another, where the exchange interaction changes.

Our future work is aimed at fabricating devices that enable us to measure the spin polarization of the layers and investigate the role of spin scattering at the metal-semiconductor interface.

Y.J. Chen, D. Basiaga, J.R. O'Brien, and D. Heiman, *Anomalous Magnetic Properties and Hall Effect in Ferromagnetic Co<sub>2</sub>MnAl Epilayers*, Appl. Phys. Lett. **84**, 4301 (2004).

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## ➤ Education

A wide range of disciplines is involved in this research – from materials science to device engineering. The scope of technologies and scientific specialties encompass the areas: MBE crystal synthesis, device fabrication, semiconductors, magnetism, low-dimensional physics, optics, diffraction, cryogenics, and high magnetic fields. A broad-based education combined with hands-on technical experience is important for future employment opportunities, especially in view of the fluctuating job market. Four graduate and three undergraduate students have been involved with this work, in addition to overlap with visiting scientists.

## ➤ Outreach

Northeastern University is strongly involved in several outreach activities. Northeastern has had a long tradition of educating urban students – they actively seek intercity and under-represented students from the Boston area. Women and under-represented minorities are active in the *Connections Program* at Northeastern to strengthen and enhance academic and career-related pathways for women and girls (middle school through college graduation) studying science, mathematics, engineering, and technology (SMET). This program also introduces young women to the university environment.